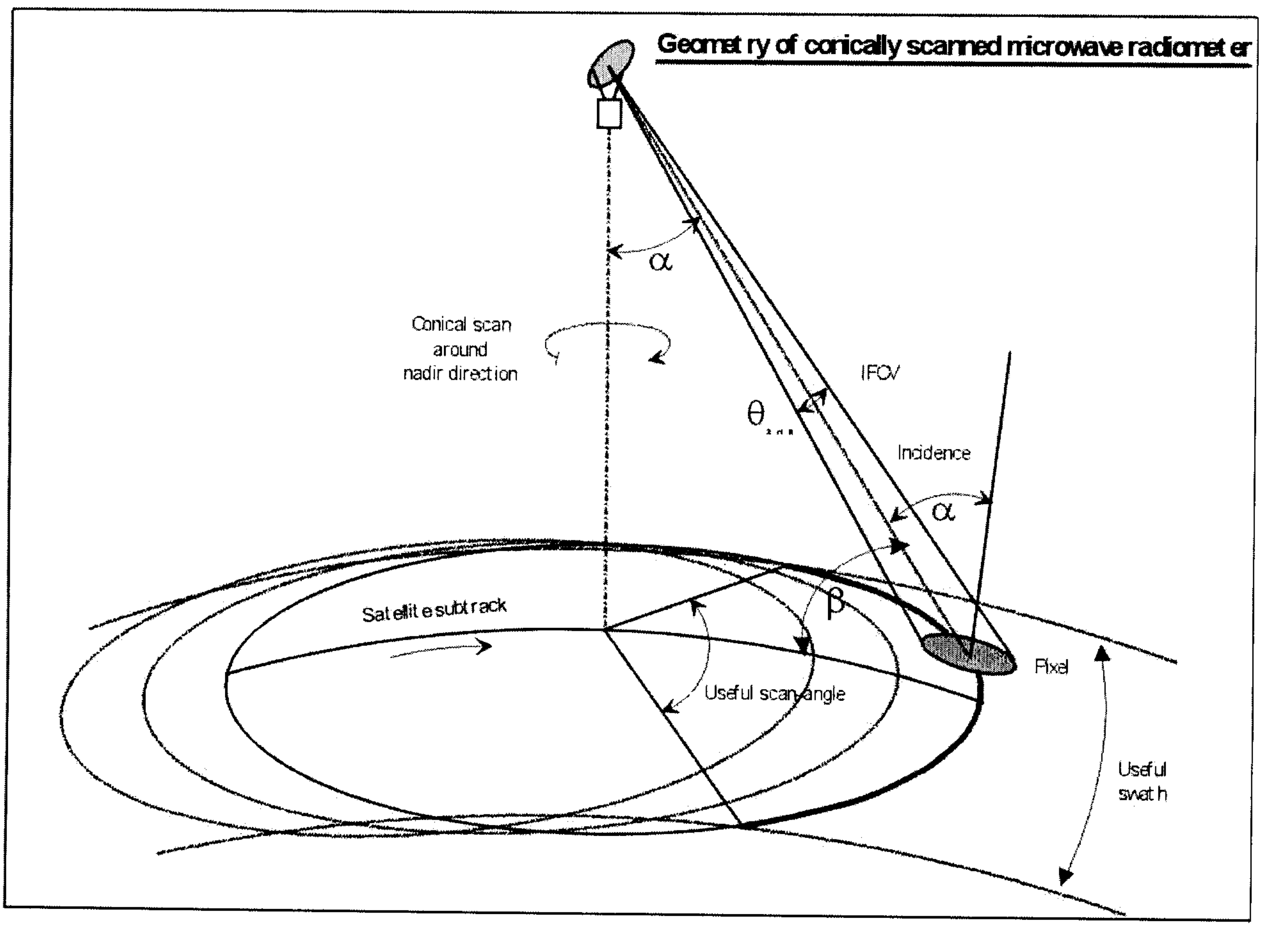
Investigation of Interference and Compatibility of 24 GHz Automotive Short Range Radar (SRR) to passive Earth Exploration Satellite Service (EESS) at 23.6-24.0 GHz

INTRODUCTION

This paper addresses the aggregate interference level from multiple SRR's as potential interferers to EESS's to demonstrate a margin of safety.

The assumptions for the calculations are considered to reflect a representative scenario for both the EESS and SRR systems based on ITU requirements as well as published SRR system descriptions.

EESS Conical Scanning Diagram



CALCULATIONS

1. Long term EESS Interference treshold (from ITU-R SA.1029-1 at 24GHz)

P_interference	<=	-163 dBW	in 100 MHz;
Equivalent to:			
PSD_rx	=	-213 dBm/Hz	

ITU-R SA.1029-1 additionally recommends, that
„in shared frequency bands (except in the absorption bands, the interference levels given above can be exceeded for less than 5% of all measurement cells within a sensor's service area in the case where the loss occurs randomly, and for less than 1% of measurement cells in the case where the loss occurs systematically at the same locations;"

2. Official Data of an EESS example „MEGHA-TROPIC" (see footnote ***)

Channel bandwidth	B	=	400MHz
Footprint diameter	D_foot	=	35.4km
Nadir angle	α	=	52.3° *(incidence angle at footprint center)*
LOS elevation angle	β	=	37.7° = 90° - α *(...in order to reach the maximum EESS antenna gain measured from ground)*
Altitude	h	=	817km
Max. Antenna Gain	G_rx	=	40dBi (efficiency 96%)
HPBW	θ	=	1.65°
dish diameter	d	=	0.65m
wavelength	λ	=	0.0126m
LOS distance	l	=	1336 km *(line of sight between EESS and SRR Transmitter)*

3. Plausibility check for above data

G_rx	≈	$38000/(\theta)^2$	=	13957 = 41.4dBi O.K.
G_rx	≈	$7 + 20\log(d/\lambda)$	=	41.25dBi O.K.
R_sat	=	h + R_earth	=	(6370+817) km = 7187km
m_earth			=	$5.98 \cdot 10^{24}$kg
G			=	$6.67 \cdot 10^{-11}$ Nm²/kg²
V_sat			=	sqrt(G * m_earth / R_sat) = 7450 m/s
t_av			=	D_foot / V_sat = 4.75s
Processing Gain G_Int	≈	sqrt(2* t_av * B)	=	61656 = 47.9dB
Polarisation Loss L_pol	=	3dB		
Receiver Noise Figure	≈	6dB		
Sensitivity	≈	kT+ NF –G_Int + L_pol	=	-174dBm + 6dB –47.9dB + 3dB
			=	-212.9 dBm/*Hz* *(good match with ITU-R)*
LOS distance l	≈	h/cos(α)	=	1336km O.K.

*** Other satellite types e.g. with higher gain and consequently smaller footprint (e.g. 45dBi antenna gain but vice versa 17km footprint diameter) give comparable results.

4. Margin Calculation *(positive sign indicates loss, negative sign indicates gain)*

	Figure	Comment
EESS Limit	-213 dBm/Hz	w.r.t. ITU-R SA.1029-1
G_rx_mean	-(+38.5) dBi	mean Antenna Gain over HPBW, 40dBi-1.5dB
Propagation Loss	-(-182.5) dB	LOS $L_{los} = 20\log(4\pi l/\lambda)$, l = 1336km
Gating	-(-3) dB	50% calculation time within cycle w.o. Transmission
Relative side lobe gain TX	-(-25.1) dB	w.r.t RPE of SRR specification $g_{tx} = -0.666*\beta$
Atmospheric Loss	- (-1.3) dB	0.16dB/km * 5km / cos (α)
SRR Transmitter PSD EIRP	-(-101.25 dBm/Hz)	w.r.t. FCC part 15 500μV/m at 3m
Margin	**+ 61,65 dB**	over entire footprint

A margin of 61,65dB corresponds to a number of 1.462.177 acceptable SRR's within the footprint.

The footprint diameter D_foot = 35.4km corresponds to an area field of View FOV = 984km^2.
The SRR transmitter area density is 1.396.368 / 984km^2 = 1.486 SRR's/km^2.

Each vehicle is equipped with 4 sensors (transmitters), which are maximum active synchronuosly.
The long-term market scenario in Yr 2020 assumes a 40% saturated penetration of vehicles with SRR's, therefore the maximum compatible vehicle density will be 1.486 / 4 / 0.4 = 929 vehicles/km^2.

Up to now this consideration has not taken the azimutal directivity and synchronuous activation of the sensors into account. The four sensors which are maximum active synchronuosly over time are mounted in the front bumper of a vehicle and have nearly the same direction towards the driver lane. Such 4 sensor cluster is used for the low speed following and precrash application and is transmitting during driving.
Other sensors which might be mounted in the rear bumper are only active when the reverse gear is choosed and therefore irrelevant for accumulation calculations.
The azimutal HPBW (half power beam width) of the sensors is less then 70°. For a receiver positioned far away the lateral separation distance between the sensors mounted in the bumper in order of 0.5meters is not a relevant factor, but the radiation patterns of the four sensors are overlapping perfectly in far field.
Such sensor cluster has therefore the same azimutal radiation pattern envelope like a single sensor. Some additional angle spread should be given in order of rounded bumper shapes and therewith an unperfect parallelity of the sensors directions is covered. We assumea figure of maximum 20°.
Therefore the sensor cluster HPBW is 90°. With respect to an uniform distribution of the vehicle directions over the azimuth s.o. can easily calculate a further margin to the described scenaria combination of 10log(360°/90°) = 6dB.
The **maximum compatible vehicle density including the azimutal directivity is 3.715 vehicles/km^2.**

5. Comparison with traffic scenarios

A highway scenario, averaged over the footprint, with 8 lanes each in a rectangular grid with intersections at 3.5 kilometers and a vehicle separation of 20 meters, has a vehicle density of 123 vehicles/km^2.
A suburban city scenario, averaged over the footprint, in a rectangular grid with 2 lanes with intersections at 250 meters and a vehicle separation of 50 meters has a vehicle density of 330 vehicles/km^2.
In the worst case, both scenarios can overlap and therefore a figure in the order of 453 vehicles/km^2 might be achieved at hot spots.

Comparing this figure with the maximum vehicle density of 3.715 vehicles/km^2 (as derived from the limits specified in ITU-R SA.1029-1) shows a **safety margin factor of 8.2 or 9.1dB.**

In case of local high density city areas additional margin is provided by the shielding effects of buildings . Scattering the transmitted power in main direction over several reflection points provides high absorption loss. A contribution of such scattered spatial emission towards the EESS direction with averaging over the total footprint should be in the order of less then 10%. Therefore the margin in footprints including a city might be reduced to 8.7dB.

6. Conclusion

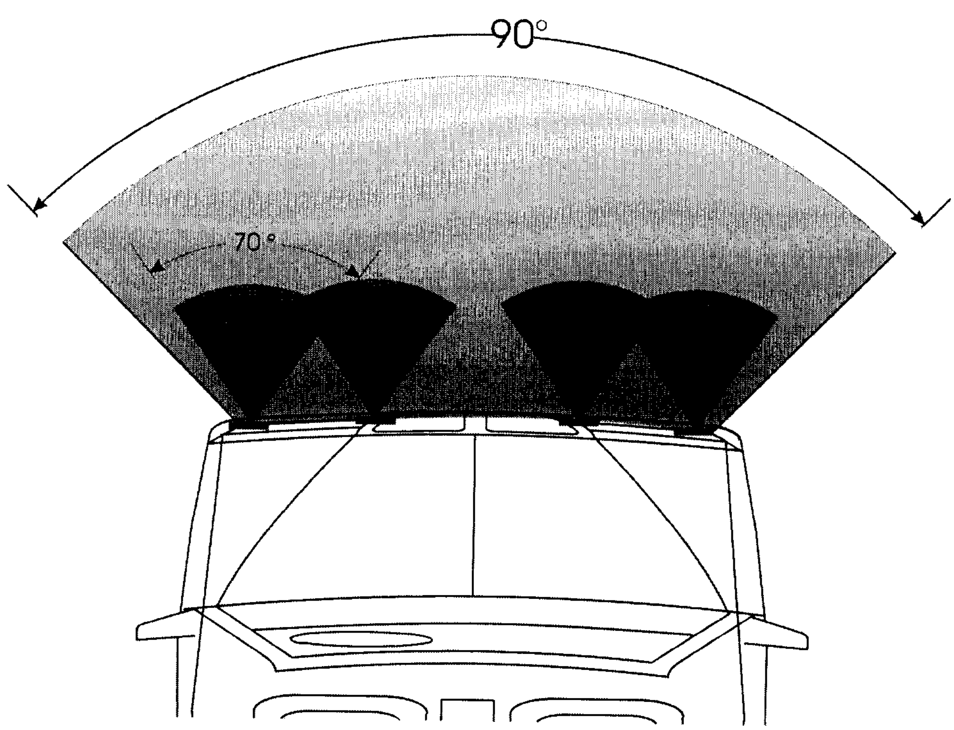
SARA believes that the traffic congestion described by the combined highway and suburban scenaria is not exceeded over time and location due to the averaged vehicle density over the total footprint of about $1000km^2$ and the entire margin of 9dB.

If a widespread hot spot congestion over the total footprint migth occur (which means a vehicle density of more then 3.715 vehicles/km^2 over the entire footprint of $984km^2$), which probability is assumed to be much less then 1 %, s.o. should consider, that this event happens randomly with respect to location and time. Furthermore the EESS period to completely round up the earth is in the order of 1 hour and 41 minutes. It is obvious that such unprobable widespread hot spot congestion has disappeared within that time.

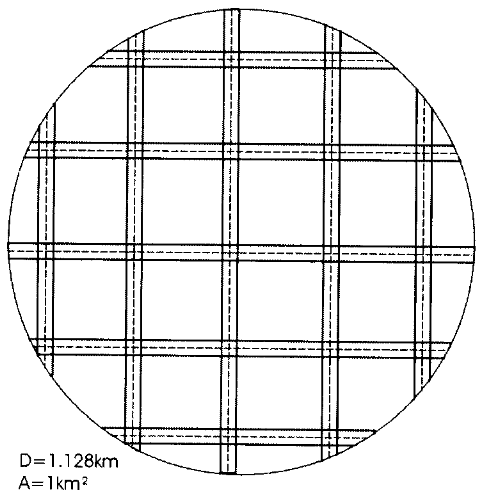
The result demonstrates that the aggregate power level of the SRR's is below the recommended long term interference limit for passive earth exploration satellites. Real life traffic scenaria show a margin in order of 9dB.

7. Attachment

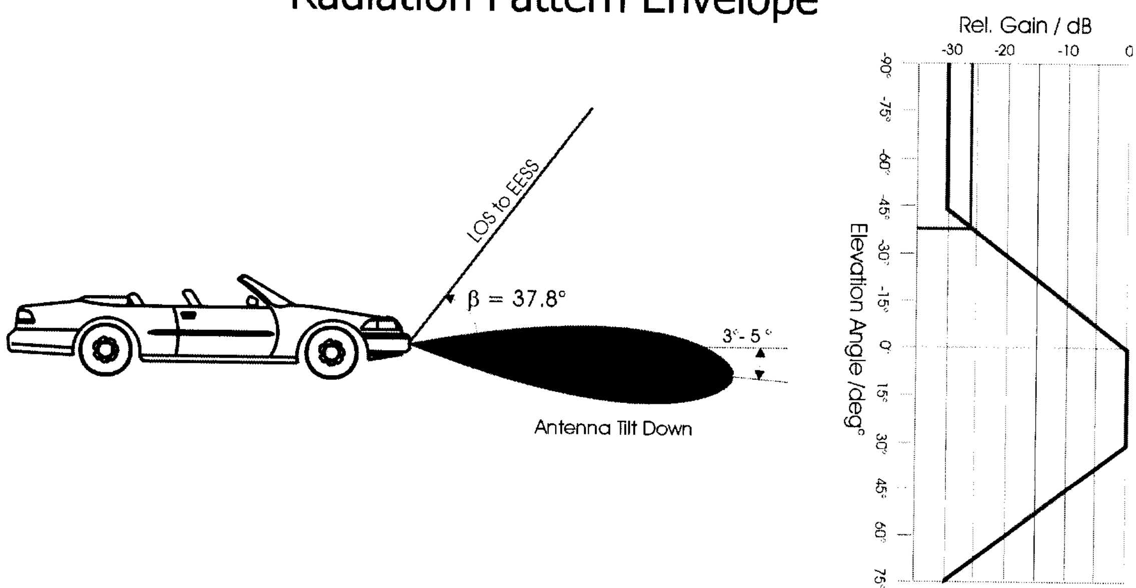
Azimutal Radiation Pattern Envelope of 4 Sensor Cluster



Suburban City Street Scenario
(rectangular grid of streets with 2 lanes with intersections at 250 meters)



Radiation Pattern Envelope



Investigation of Interference and Compatibility of 24 GHz Automotive Short Range Radar (SRR) to Radio Astronomy (RA) at 23.6-24.0 GHz

INTRODUCTION

This paper addresses the interference level from SRR's as potential interferers to RA to demonstrate compatibility.

The assumptions for the calculations are considered to reflect a representative scenario for Radio Astronomy and SRR systems. Since RA Observatories are in general located in remote areas, we conclude a single vehicle entry is representative.

Interference Criteria

ITU-R RA.769-1 recommends a spectral power flux density threshold level of $-232.5 dBWm^{-2}Hz^{-1}$ for the continuum observations at 23.6-24GHz. The continuum observations are the most sensitive compared with line observations.
The limit criteria is defined with respect to an isotropic receiver (0dBi). The corresponding spectral power density is –251.5dBm/Hz.

Such best case sensitivity of –251.5dBm/Hz can only be achieved under the following conditions:

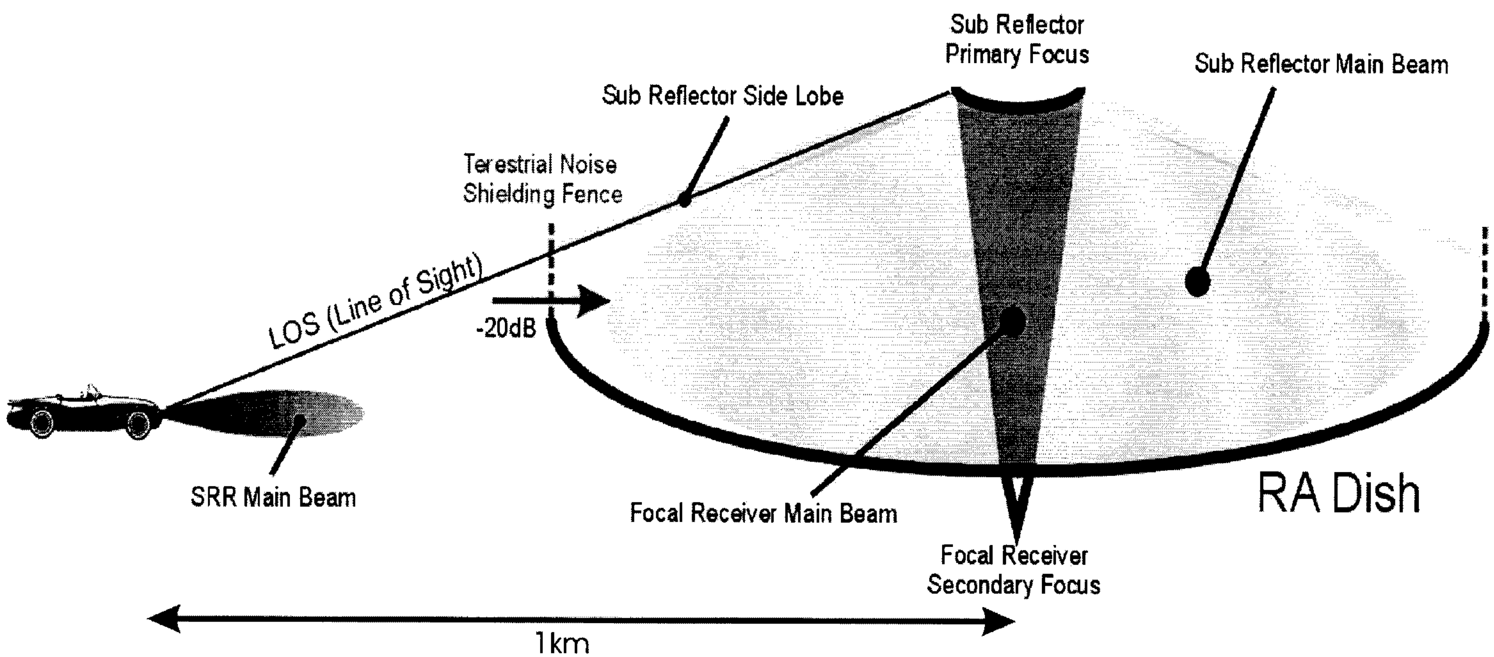
a) Fluctuations of terrestrial and atmospheric noise affecting the system temperature over the measurement average time can completely be compensated via calibration.

b) The elevation of the dish is more then 30° to avoid system temperature increase coming from terrestrial noise.

c) The water vapor content within atmosphere has to be nearly zero, so that only oxygen is responsible for the remaining attenuation and the corresponding degradation of the system sensitivity. Such environmental condition can only be achieved in very cold and dry winter nights or on top of high mountains.

The calculations below take into consideration the degradation of sensitivity over the elevation angle as well as due to a a very low degree of water vapor density in atmosphere. S.o can consider that with 90° elevation in zenith position the sensitivity in the table below is -247,8dBm/Hz (see line1 / column H). This nearly fits to the ITU Requirement of -251dBm/Hz.
Taking into account that for elevation above 30° our calculation shows a margin of minimum 6,5dB, the 3dB difference of our best case sensitivity of –247,8dBm/Hz to the ITU-R of –251,5dB/Hz is not from relevance.

Single Entry Interference Scenario

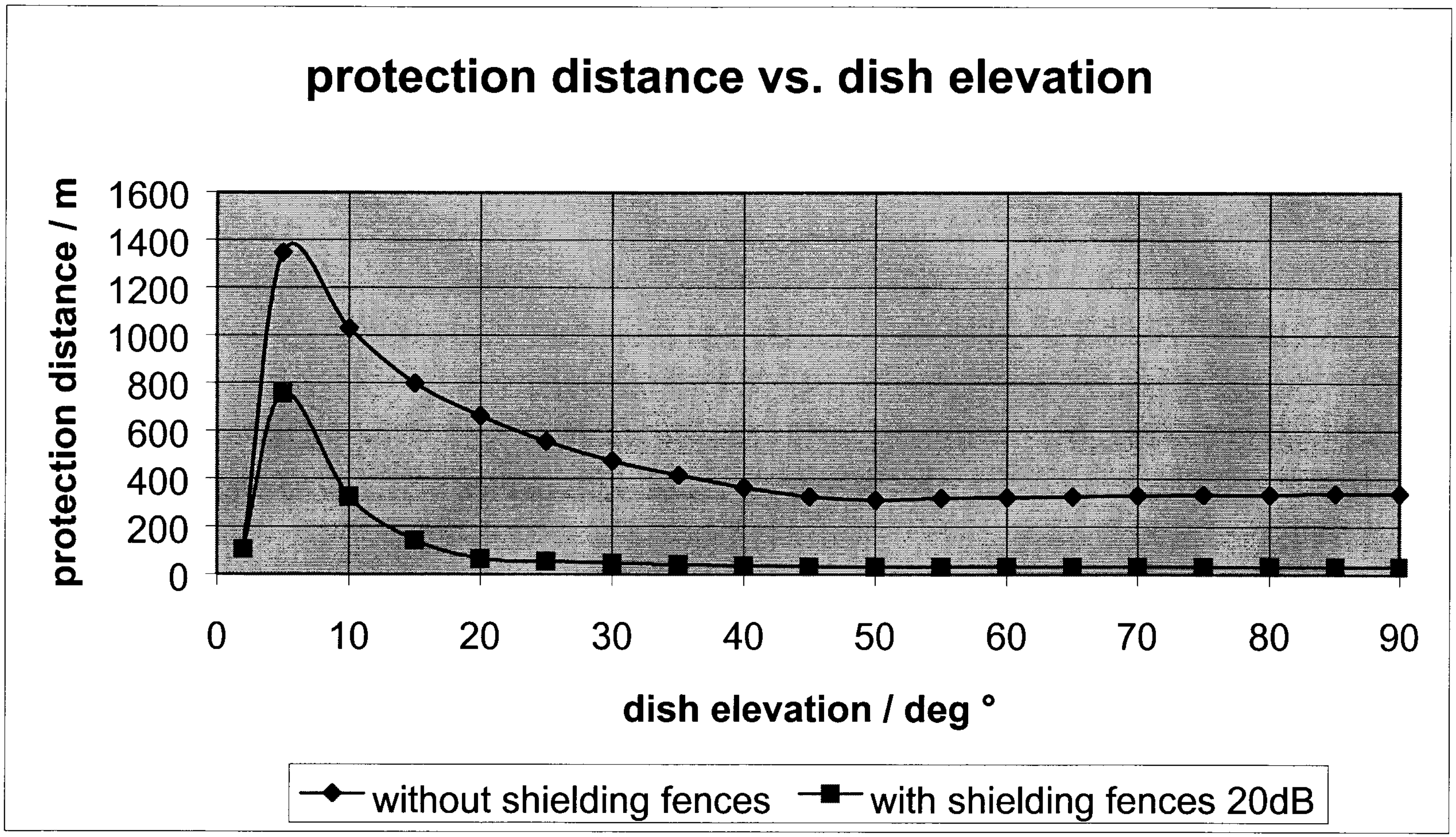


	A	B	C	D	E	F	G	H	I	H	J	K	L	M	N	O
Line #	Dish angle w.r.t. ground in° (90° = zenith)	LOS path length along atmosphere with 5km height in km	L_atm_dB Atmos. Loss in dB 0.16dB/km (7.5mm^2 H2O)	T_atm in K (L-1)* T_amb T_amb =273K	T_cosm in K	T_terr in K (supressed due to shielding fence vs. Spillover)	T_rec in K	T_sys in K	Integration Gain in dB 2000s 400MHz sqrt(2*f*t)	PSD Sensitivity in dBm/Hz 0.1kT_sys	mean Antenna sidelobe gain in dB (ITU-R SA.509-2 + F.1245-1)	Shielding Loss in dB due to dish fences w.r.t elevation	Topolog. Clutter Loss in dB for 1km distance	LOS Propag. Loss in dB w.r.t. 1km	Polarisation Loss in dB	max. PSD_Tx in dBm/Hz w.o. shielding
1	90	5,00	0,8	55,2	2,5	0	50	107,7	59,5	-247,8	-13,0	20	20	120	3	-91,8
2	85	5,02	0,8032	55,5	2,5	0	50	108,0	59,5	-247,8	-13,0	20	20	120	3	-91,8
3	80	5,07	0,8112	56,1	2,5	0	50	108,6	59,5	-247,7	-13,0	20	20	120	3	-91,7
4	75	5,18	0,8288	57,4	2,5	0	50	109,9	59,5	-247,7	-13,0	20	20	120	3	-91,7
5	70	5,32	0,8512	59,1	2,5	0	50	111,6	59,5	-247,6	-13,0	20	20	120	3	-91,6
6	65	5,52	0,8832	61,6	2,5	0	50	114,1	59,5	-247,5	-13,0	20	20	120	3	-91,5
7	60	5,77	0,9232	64,7	2,5	0	50	117,2	59,5	-247,4	-13,0	20	20	120	3	-91,4
8	55	6,10	0,976	68,8	2,5	0	50	121,3	59,5	-247,3	-13,0	20	20	120	3	-91,3
9	50	6,53	1,0448	74,3	2,5	0	50	126,8	59,5	-247,1	-13,0	20	20	120	3	-91,1
10	45	7,07	1,1312	81,2	2,5	0	50	133,7	59,5	-246,8	-12,3	20	20	120	3	-91,5
11	40	7,77	1,2432	90,5	2,5	0	50	143,0	59,5	-246,5	-11,1	20	20	120	3	-92,5
12	35	8,71	1,3936	103,3	2,5	0	50	155,8	59,5	-246,2	-9,6	20	20	120	3	-93,6
13	30	9,99	1,5984	121,5	2,5	0	50	174,0	59,5	-245,7	-7,9	20	20	120	3	-94,8
14	25	11,81	1,8896	148,8	2,5	0	50	201,3	59,5	-245,1	-5,9	20	20	120	3	-96,1
15	20	14,58	2,3328	194,1	2,5	0	50	246,6	59,5	-244,2	-3,5	20	20	120	3	-97,7
16	15	19,21	3,0736	281,0	2,5	10	50	343,5	59,5	-242,7	-0,4	15	20	120	3	-99,3
17	10	28,44	4,5504	505,4	2,5	15	50	572,9	59,5	-240,5	4,0	10	20	120	3	-101,5
18	5	54,70	8,752	1775,2	2,5	100	50	1927,7	59,5	-235,3	11,5	5	20	120	3	-103,8
19	2	252,52	40,4032	2995318,9	2,5	200	50	2995571,4	59,5	-203,3	21,5	0	20	120	3	-81,8

	A	H	J	K	L	M	N	O	P	Q	R	S
Line number	Dish angle w.r.t. ground in° (0° = zenith)	PSD Sensitivity in dBm/Hz 0.1kT_sys	mean Antenna sidelobe gain in dB (ITU-R SA.509-2 + F.1245-1)	Shielding Loss in dB due to dish fences w.r.t elevation	Topolog. Clutter Loss in dB for 1km distance	LOS Propag. Loss in dB w.r.t. 1km	Polarisation Loss in dB	max. PSD_Tx in dBm/Hz w.o. shielding	Remaining Margin w.r.t FCC part 15 UWB limit -101.25dBm/Hz equivalent to 500µV/m at 3m **w.o. shielding w.r.t 1km**	Remaining Margin w.r.t FCC part 15 UWB limit -101.25dBm/Hz equivalent to 500µV/m at 3m **with shielding w.r.t 1km**	Minimum Protection distance in m **w.o.** shielding	Minimum Protection distance in m **with** shielding
1	90	-247,8	-13,0	20	20	120	3	-91,8	9,45	29,45	337	34
2	85	-247,8	-13,0	20	20	120	3	-91,8	9,45	29,45	337	34
3	80	-247,7	-13,0	20	20	120	3	-91,7	9,55	29,55	333	33
4	75	-247,7	-13,0	20	20	120	3	-91,7	9,55	29,55	333	33
5	70	-247,6	-13,0	20	20	120	3	-91,6	9,65	29,65	329	33
6	65	-247,5	-13,0	20	20	120	3	-91,5	9,75	29,75	325	33
7	60	-247,4	-13,0	20	20	120	3	-91,4	9,85	29,85	322	32
8	55	-247,3	-13,0	20	20	120	3	-91,3	9,95	29,95	318	32
9	50	-247,1	-13,0	20	20	120	3	-91,1	10,15	30,15	311	31
10	45	-246,8	-12,3	20	20	120	3	-91,5	9,78	29,78	324	32
11	40	-246,5	-11,1	20	20	120	3	-92,4	8,80	28,80	363	36
12	35	-246,2	-9,6	20	20	120	3	-93,6	7,65	27,65	414	41
13	30	-245,7	-7,9	20	20	120	3	-94,8	6,48	26,48	474	47
14	25	-245,1	-5,9	20	20	120	3	-96,2	5,10	25,10	556	56
15	20	-244,2	-3,5	20	20	120	3	-97,7	3,58	23,58	663	66
16	15	-242,7	-0,4	15	20	120	3	-99,3	1,95	16,95	799	142
17	10	-240,5	4,0	10	20	120	3	-101,5	-0,25	9,75	1029	325
18	5	-235,3	11,5	5	20	120	3	-103,8	-2,58	2,42	1345	756
19	2	-203,3	21,5	0	20	120	3	-81,8	19,48	19,48	106	106

Conclusion:

- For normal RA measurement conditions with an elevation of more then 10° over ground the protection requirement is never exceeded.
- For RA measurements with an elevation angle of 5° the worst case protection distance is 1.350m without taking any shielding into account. With a possible shielding of 20dB the protection distance keeps also for such singular case below the protection requirement.


protection distance vs. dish elevation
protection distance / m
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
dish elevation / deg °
without shielding fences
with shielding fences 20dB